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Design Based Improvement in a Three Pan *Jaggery* Making Plant For Rural India

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Abstract

Jaggery making is among the major agro processing industries found in rural India. Nearly 50% of total sugarcane produced in the country is used to manufacture about 8 million tonnes of jaggery, which is known to be the most nutritious agent among all sweeteners. Jaggery making plants are generally small units fabricated by local artisans and run by villagers in different parts of India. These plants are designed and fabricated on the basis of age old expertise without any technical support. Bagasse is used as fuel in these units to boil the sugarcane juice. Due to the crude and improper design, energy losses are high in these units resulting into higher fuel consumption. In order to reduce the losses and cut down the consumption of bagasse, an efficient three pan jaggery making plant is designed and studied. The improved plant and the conventional plant are compared on the basis of four parameters viz. jaggery production, baggase consumption, emissions and temperature of exhaust. The Improved unit resulted in about 12% reductions in bagasse consumption, about 23% increases in jaggery production capacity, lesser emissions and comparatively lower exhaust gas temperature.

Keyword: Jaggery; three pan Jaggery making unit; Bagasse.

1. INTRODUCTION

Jaggery (also called as gur in India, Desi in Pakistan, Panela in maxico and South America) is a traditional sweetener which is produced in addition to sugar from sugarcane. It is produced by boiling off sugarcane juice in small *jaggery* making plant to solid *jaggery*, which contains 65-85% sucrose [1]. Compared to other sweeteners, *jaggery* contains iron (11%), calcium (0.4%), phosphorous (0.045%), glucose and fructose (10-15%), protein (0.25%) and fat (0.05%) [2]. *Jaggery* is prepared in small plants from sugarcane juice in rural areas. These plants basically consist of an underground furnace over which sugarcane juice is boiled off in large boiling pans. The sugarcane juice is produced by crushing of sugarcane in crushers and the bagasse is left over. After drying in sun, the left over bagasse is used as fuel in the furnace. The exhaust gases are released into the atmosphere through a vertical chimney. The sugarcane juice in the boiling pans is further clarified during the boiling stage it is mostly done by using lime (calcium hydroxide). Calcium acts as complexing agent and form scum, which is removed from time to time during boiling. Lime addition simultaneously increases the normal pH of juice from 5.2-5.4 to 6.0-6.4 [3].

It has been observed that furnaces and chimney of these plants are not properly designed, large proportion of produced heat is wasted and dense smoke is generally observed through the chimney of these conventional plants, as a result, bagasse consumption is very high in these plants. *Jaggery* making is a dominant cottage industry in India engaging over 2.5 million people. In case the bagasse is used optimally, a significant quantity of it can be saved, which may be further put to other useful applications such as paper and pulp industry, mushroom growing, as a direct charged fuel and for the production of ethanol, n-butanol etc, thus leading to additional income to the people involved in this activity [3-5]. Apart from its direct fuel use, bagasse gives rise to: pulps for rayon and absorbent products; particleboards and fibreboards; fuel briquettes, charcoal and producer gas; animal feeds (Bago-molasses); edible mushrooms (notably *Pleurotus*); chemicals (furfural, furfuryl alcohol, xylitol, Sucrolin, ethanol), activated carbon, and 'hydrolysed pith' poultry feed. Cane molasses is mostly used for making ethanol (and hence chemicals derived by dehydration, oxidation or modification), many other fermentation products and various animal feeds; novel products include ephedrine hydrochloride, Ifopol biocide and Nitromiel explosive. Sugarcane trash (tops, leaves) are used as fuel, mulch, and animal feeds. Filter press mud can be used as fertilizer, and is the usual source of cane wax; it can also be used in making biogas, animal feed and cement, and (mixed 1:12 with bagasse) in boilers, where it facilitates mechanical removal of ash. Bagasse ash is also used in making glass [6]. Besides this the saved bagasse may be used in other industries to be used as fuel and may provide Clean Development Mechanism (CDM) advantage. CDM provides an incentive to invest in emission reduction projects in developing countries to achieve reduction in CO_2 emissions at lowest cost that also promotes sustainable development in the host country. Bagasse cogeneration projects could be of interest under the CDM as they directly displace greenhouse gas emissions while contributing to sustainable rural development [7].

Process of *jaggery* making is almost same in every part of the Indian sub continent but there is a difference in the design of plants being used for *jaggery* making. In the northern Indian states of Uttar Pradesh and Uttarakhand, three pan *jaggery* making plant is popular, however in the state of Maharashtra single pan and four pan plants are popular. It is evident that bagasse can be saved for other application only when the combustion & thermal efficiency of the *jaggery* plants are improved. Anwar [8] has suggested providing parallel fins at the bottom of boiling pans to enhance the heat transfer. Charging of bagasse too has an impact on the thermal efficiency of *jaggery* making plants [9]. Therefore, to improve the performance of *jaggery* making plants, more technical intervention is required to improve its combustion efficiency and thermal efficiency, making the process more efficient, profit making and environment friendly [10-12]. Also the technical knowhow involved in the manufacture of *jaggery* is very crude which can be improved through application of modern technology taking into consideration the ecological factors. Because of great importance of *jaggery*, proper care should be taken to improve the *jaggery* industry and sugarcane cultivation for *jaggery* making, which is presently in a neglected state [13-14]. An improved three pan *jaggery* making plant is therefore designed and studied in this paper.

2. EXPERIMENTAL

To conduct the experimental trials, two actual *jaggery* making plants were fabricated, one with conventional design and other with improved design of furnace, fire gratings and chimney with exhaust gas damper.

2.1 Conventional design

A conventional three pan *jaggery* making plant consists of one vertical three roller sugarcane crusher, three mild steel boiling pans of 457-559 mm thickness and 1524-1575 mm diameter. Ordinary masonry bricks, cement, sand and earth clay is used for its construction. The process of *jaggery* making in a three pan plant is a continuous process and requires 7-8 skilled manpower to work on. During the start of process all three boiling pans are filled with sugarcane juice and fuel (bagasse) is charged through a charging hole below the boiling pan-3. The maximum temperature is found below the boiling pan-3, which is around 1000 ^{0}C. Heat transfer under this boiling pan is mainly through convection and radiation. Rest other two boiling pans also fetch some heat through convection from the hot flue gases moving towards the chimney under a continuous draft. Cleaning of scum during the process is done on first two pans using calcium chloride, sodium hydroshulphide / wild lady finger stems etc. After the sugarcane juice in the boiling pan-3 is converted into solid *jaggery* by evaporation, the second batch of pre-heated sugar cane juice of boiling pan-2 is poured into boiling pan-3 and preheated sugar cane juice of boiling pan -1 is poured into pan-2 while fresh sugar cane juice comes into the boiling pan-1 through a pipe from the sugar cane crusher. In this way a continuous process of *jaggery* making is initiated with sugar cane juice finally getting evaporated into solid *jaggery* in boiling pan-3 and fresh juice getting preheated in the rest two boiling pans. From the data collected from local farmers, it is found that on an average 100 kg of sugarcane produces 10-12 kg of *jaggery* in north Indian areas and 600–800 kg of *jaggery* is produced in a single day with these conventional three pan *jaggery* making plants. Process flow chart of a typical three pan *jaggery* making process is shown in Fig.1.

2.2 Improved design

Improvement in the three pan *jaggery* making plant is stressed mainly towards the better design of furnace and chimney which would improve the combustion of fuel (bagasse) thereby increasing in heat addition to the process. The improved design of three pan *jaggery making plant* is shown in fig. 1. For the constructing of furnace in the improved plant, fire bricks (40-50% alumina) are used in place of ordinary masonry bricks. To achieve the intimate mixing of fuel and combustion air, a cast iron fire grate is provided in the furnace. The fuel (bagasse) charged into the furnace, falls on these grates and burns combining with air intake through furnace front wall openings as well as that entering through the bottom openings of fire grates. Also the ash gets automatically dropped through the grating and can be easily taken out periodically. Another major design improvement is the improved chimney. The improved chimney has circular cross section with an optimum height. The height of the chimney is calculated through experimental and practical methods. The improved chimney provides a smooth flow of exhaust gases with sufficient draft. Two sliding exhaust gas dampers made of M.S plate, are provided in the chimney to control the draft.

Fig.1 Improved three pan *jaggery* making plant

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THEORY

Exact calculation of thermal efficiency based on theoretical relations is very difficult in case of three pan *jaggerey* making plants, as some the parameters are not known and controlled efficiently e.g. optimum fuel charging rate, specific heat of sugarcane juice from boiling pan-1 to boiling pan-3 etc. However, some work has been done to find convective heat transfer coefficient of *jaggery* during boiling from sugarcane juice to solid *jaggery* [15]. A comparison of thermal efficiency and combustion efficiency can only be made based on the *jaggery* production, fuel consumption, temperature of exhaust gases and quality of exhaust gases. In context to this comparative performance trials were conducted on a conventional three pan *jaggery* making plant and improved plant to evaluate bagasse consumption and *jaggery* production quantitavily and chimney smoke qualitatively. Both the plants were run in similar conditions during a *jaggery* production shift (normally 16-18 hrs.). Observations were made at regular intervals for a batch of fixed volume of fresh sugar cane juice which was charged into the boiling pan-1. The weight of bagasse consumed in the furnace for the charged juice and quantity of *Jaggery* produced out of it were noted at regular intervals. Smoke number was measure using a Testo, smoke meter, CO_2% with Horiba PG-250 gas analyzer and temperature of the flue gases were monitored with a K-type thermocouple.

RESULTS AND DISCUSSION

Experimental trails were conducted on both the conventional and improved three pan *jaggery* making plant, consumption of fuel (baggase) and production of *jaggery* was observed. The consumption of baggase per kg. of jaggery produced in conventional three pan *jaggery* making plant is 2.26 kg i.e. 2.26 kg. of fuel is used to produce one kg. of *jaggery*. Whereas, in improved three pan *jaggery* making plant 1.99 kg. of fuel is used to produce one kg. of *jaggery*, which is almost 12% reduction in fuel consumption. Per day production capacity has also increased from 762 kg. of *jaggery* to 937 kg. of *jaggery*, which is almost 23% increase in production capacity as shown in table 1 and 2. Increased percentage of CO_2 in the exhaust gases signifies the better combustion of fuel in the plant furnace, as more CO_2 implies less CO. The improved plant has comparatively high CO_2% then conventional three pan *jaggery* making plant. A comparison of exhaust gas emissions, in terms of CO_2 % for both the designs is shown fig. 3.

Table.1 Performance of conventional plant

Plant type	**Time** (hr:min)	**Quantity of sugarcane juice** (kg.)	**Consumption of Bagasse** (kg.)	***Jaggery* production** (kg.)
Conventional	5:13	1500	418	178
Conventional	6:05	1500	648	288
Conventional	6:30	1500	657	296

Table.2 Performance of improved plant

Plant type	**Time** (hr:min)	**Quantity of sugarcane juice** (kg.)	**Consumption of Bagasse** (kg.)	***Jaggery* production** (kg.)
Improved	6:26	1800	570	279
Improved	5:41	1800	673	316
Improved	6:13	1800	625	342

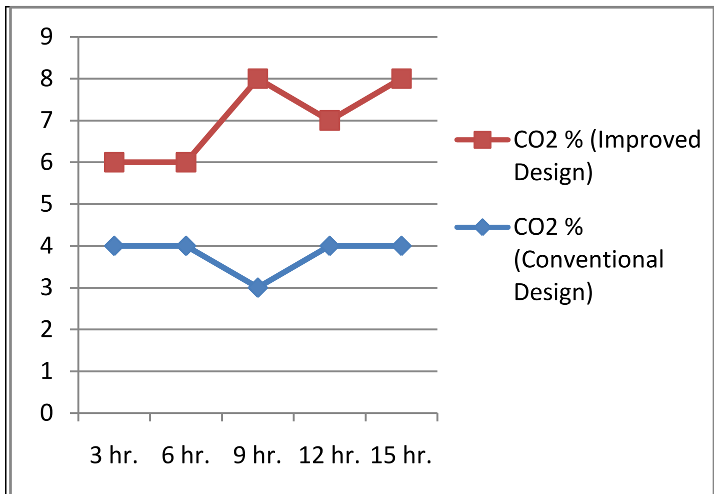


Fig.2. C02% in exhaust gas from chimney of improved and conventional *jaggery* making plant

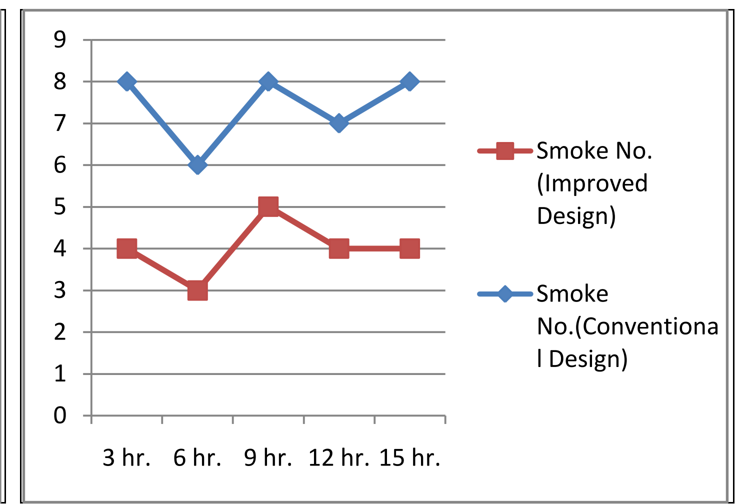


Fig.3 Smoke No. of exhaust gases of improved and conventional *jaggery* making plant

Smoke no. signifies the concentration of unburnt carbon particles in the exhaust gas; high smoke no. refers to more unburnt carbon particles. Exhaust of the improved plant has shown lower smoke numbers as compared to conventionally designed plant. A comparison of the Smoke numbers is shown fig.4.

Temperature profile of exhaust gases for both the improved and conventional designed plants is shown in fig 5. Temperature of the exhaust gases is directly related to the amount of heat being unutilized in the process and it is one of the major losses of the process. Temperature of the exhaust gases from improved furnace has lower temperature profile during the entire process as compared to the conventional design, which reflects that more heat is being used from the combustion of baggase to the process of making *jaggery*. These results can be directly correlated to the increase in thermal efficiency and combustion efficiency of the improved three pan plant.

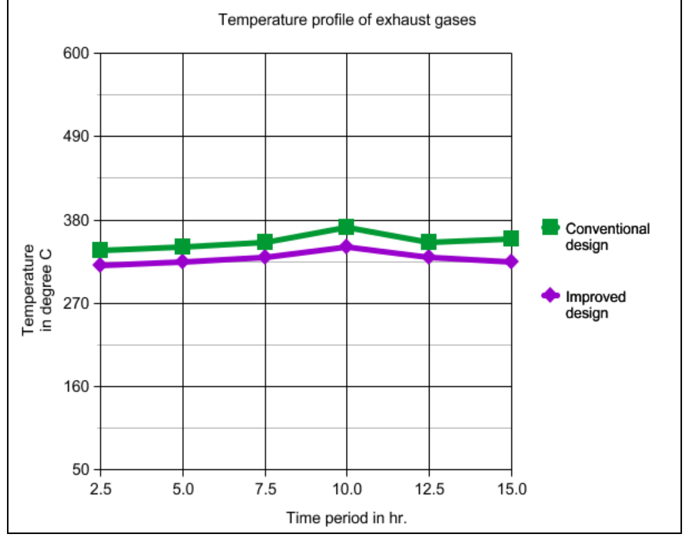


Fig.4 Temperature profile of the exhaust gases in ^{0}C from improved & conventional *jaggery* making plant

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Conclusion

The experimental results shows that the three pan *jaggery* making plant, made with fire bricks, fire grates, improved chimney and dampers can significantly improve the performance of *jaggery* making such plants. Per shift sugarcane processing capacity has increased from 4500 lit. to 5400 lit. and by working for 30 min. extra in a shift, 23% extra *jaggery* can be prepared in the improved plant with 12% saving of fuel. The improved design has also resulted in better combustion of baggase in the furnace as the $C0_2$% and Smoke no. is comparatively better than that of conventional design plant. Therefore, it can be concluded that the improved three pan *jaggery* making plant has improved thermal efficiency and impinges comparatively lesser pollution hazard to the atmosphere than the conventional plant. However, still there is a large scope of improvement in the performance of such plants by improving the combustion of fuel in the furnace, implementing better heat transfer systems and heat recuperation systems and by using filters and scrubbers in the system, emissions can be reduced to very low levels.

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